

9.3 **A NUMERICAL STUDY OF TROPICAL SEA-AIR INTERACTIONS  
USING A CLOUD RESOLVING MODEL COUPLED WITH AN OCEAN MIXED-LAYER MODEL**

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## 1. INTRODUCTION

Coupling a cloud resolving model (CRM) with an ocean mixed layer (OML) model can provide a powerful tool for better understanding impacts of atmospheric precipitation on sea surface temperature (SST) and salinity (Li et al. 2000). The objective of this study is twofold. First, by using the 3-D CRM-simulated (the Goddard Cumulus Ensemble model, GCE) diabatic source terms, radiation (longwave and shortwave), surface fluxes (sensible and latent heat, and wind stress), and precipitation as input for the OML model, the respective impact of individual component on upper ocean heat and salt budgets are investigated. Secondly, a two-way air-sea interaction between tropical atmospheric climates (involving atmospheric radiative-convective processes, Tao et al. 1999) and upper ocean boundary layer is also examined using a coupled 2-D GCE and OML model. Results presented here, however, only involve the first aspect. Complete results will be presented at the conference.

## 2. MODEL

The GCE model used in this study is an anelastic, nonhydrostatic model that has been broadly used to study cloud-radiation interaction, cloud-environment interaction, and air-sea interaction. The cloud microphysics include a two-category liquid water scheme (cloud water and rain), and a three-category ice microphysics scheme (cloud ice, snow and hail/graupel). The model also includes solar and longwave radiative transfer processes. The model structure was detailed in Tao and Simpson (1993). The OML model used in this study (the same as that used by Li et al. 2000) is a mixed-layer model embedded within a multilevel ocean circulation model originally developed by Adamec et al. 1981. The OML model solves equations for mixed-layer depth, temperature, and salinity with imposed (input) upper boundary forcing such as radiation and surface heating fluxes and surface fresh water (precipitation minus evaporation rates) flux.

## 3. RESULTS

The 3-D GCE model-simulated surface quantities for three convective episodes during TOGA-COARE have been used as input forcing to drive the OML model. TOGA-COARE observations are used as initial and boundary conditions for the coupled model as well as to validate the model results. The three episodes studied are episode 1, December 10-17, 1992; episode 2, December 19-27, 1992; and episode 3, February 9-13, 1993. Episode 1 is prevailed by easterly, while episodes 2 and 3 evolve in the system mainly associated with strong westerlies. A series of sensitivity simulations have been performed for each episode to study the impact by the individual input forcing on upper ocean heat and salt budgets. However, only the sensitivity results for episode 2 will be shown here since qualitatively similar impacts are found among the three episodes. A series of time evolution of horizontal mean mixed layer temperature (T), depth (h), and 3-m salinity (S) for episode 2 are shown in Figs. 1, 2, and 3, respectively. In each figure, thick dotted lines are the numerical results with all the atmospheric input forcing, while the thick solid lines are the TOGA-COARE observations (only for T and S). The six other curves correspond to the six sensitivity simulations excluding one of the six input forcing terms, respectively.

General features for results with all the forcing terms included are discussed first. Sea surface temperature varies diurnally (in all three episodes) that are mainly due to diurnal solar radiation variations (Fig. 1). This diurnal variation in sea surface temperature then forms a diurnal variation in thermal instability for the upper sea surface layer, i.e., a thermally stable layer at daytime and a thermally unstable layer at night. Consequently, strong (deep) surface layer mixing occurs at nighttime due to thermal instability, while mixing is confined to a shallow layer in the daytime due to thermal stability. Time variation of the horizontal-mean mixed-layer depth (Fig. 2) is hence found out of phase with that of SST.

This mixed-layer depth, further modified by the surface wind speed, is found fluctuating with small amplitude (shallow mixed-layer) in episode 1 with weak surface wind speed, and oscillating with large amplitudes (deep mixed-layer) in both episodes 2 and 3 due to strong surface wind speeds by westerlies (not shown). However, the diurnally oscillating SST is modified by the mixing process in an opposite way, i.e., the lightly (highly) oscillating SST with small (large)

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amplitude in episode 2 (1, not shown) corresponds to strong (weak) mixing in the ocean surface layer.

Time evolution of horizontal-mean surface salinity ( $S$ , Fig. 3) is found positively correlated with that of the mixed layer depth. A stronger (weaker) mixing in the boundary layer brings up more (less) salty water from below to upper sea surface layer and generates higher (lower) surface salinity. Salinity (through diffusion) also plays an important role in affecting upper layer mixing. In episode 2, high surface salinity tends to diffuse downward and intensifies the mixing process, while low surface salinity found in episode 1 might significantly stabilize the mixing process (very shallow  $h$ , not shown). In terms of impacts on mixed-layer depth, the saline effect may even play a stronger role than the thermal effect does because the expansion coefficient of ocean water density by salinity ( $0.00075 \text{ 1/PSU}$ ) is larger than that by temperature ( $0.0002 \text{ 1/}^\circ\text{C}$ ) while variations in temperature and salinity are comparable in magnitude. The numerical SST simulations generally agree well with the SST observations, while the salinity simulations differ from the observations both qualitatively and quantitatively. The discrepancy in salinity may be due to the possible poor salinity observations and the biased numerical precipitation quantities (see later discussion).

Impacts by the individual forcing term (shortwave, longwave radiation, sensible, latent heating, wind stress, and precipitation, respectively) on upper ocean temperature, mixed-layer depth, and salinity are found significant and reasonable. Temperature ( $T$ ) increases when either latent heat flux, sensible heat flux, longwave radiation, or precipitation is excluded, while it decreases without shortwave radiation (Fig. 1). As wind stress is excluded,  $T$  is found increased in the first two days, but decreased in later days. The net surface fluxes (positive or negative) along with a reduced mixed-layer depth (without wind stress) determines the impact on the  $T$  distribution (enhanced or weakened) by wind stress.

For mixed-layer depth  $h$ , it decreases as either latent heat flux, sensible heat flux, longwave radiation, or wind stress is omitted, while it increases as either shortwave or precipitation is left out (Fig. 2). The decrease in  $h$  is either due to a thermal stability (increased surface temperature) or a weak mixing without wind stress. On the other hand, the increase in  $h$  is either due to a thermal instability (reduced surface temperature) or a saline instability (enhanced surface salinity without precipitation). Salinity,  $S$  is found increased without precipitation nor shortwave radiation, but decreased without latent heat flux, sensible heat flux, longwave radiation, nor wind stress (Fig. 3). As mentioned earlier,  $S$  is again shown positively correlated with  $h$ .

#### 4. SUMMARY

Here, we mainly discussed the general features of the upper ocean heat and salt fields as well as the associated impacts by the 3-D GCE model-simulated forcing terms. Findings involving in a two-way air-sea

interaction between tropical atmospheric climates and ocean mixed layer will also be presented during the conference meeting. In addition, impacts due to numerical scale factor and model domain size will be discussed as well.

#### 5. REFERENCES

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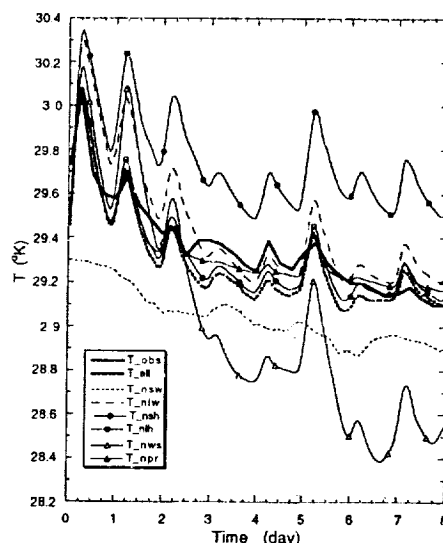


Fig. 1 Time evolution of horizontal mean mixed layer temperature ( $^\circ\text{C}$ ) for period 2. Thick solid line denotes the TOGA-COARE observation and thick dotted line denotes numerical result with all forcing terms. "nsw", "nlw", "nsh", "nlh", "nws", and "npr" denote numerical results excluding solar radiation, longwave radiation, sensible heat flux, latent heat flux, wind stress, or precipitation, respectively.

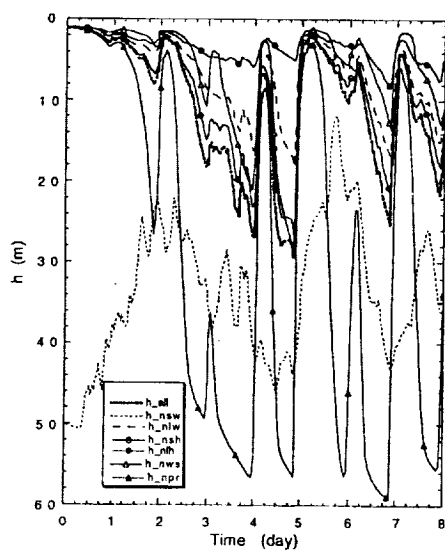


Fig. 2 Same as Fig. 1 except for the mixed-layer depth (m), but no TOGA-COARE observation available.

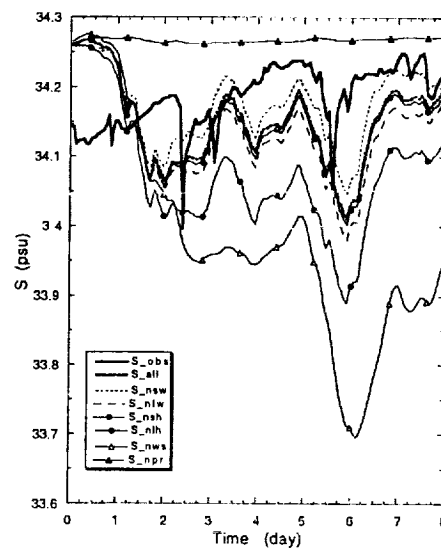


Fig. 3 Same as Fig. 1 except for the 3-m salinity (psu – practical salinity unit).